

A plant nutrition strategy for *ex-situ* conservation based on “Ecological Similarity”

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Abstract: This paper reviewed a large scale conservation work of rare and endangered plants currently conducted in main botanical gardens in China, and the existed, predictable and neglected problems on plant growth and reproduction in *ex-situ* conservation process. Considered the status quo in plant *ex-situ* conservation, a nutritional strategy on the plant conservation was proposed based on ‘Ecological Similarity’. Its main idea was that the *ex-situ* conservation plants coming from natural ecosystem were compulsively allocated in the agro-ecosystems and would return to natural ecosystem ultimately. Therefore, research on plant nutrition of the *ex-situ* conservation plants should neither just pursue yield and quality as that in agro-ecosystems nor merely stay on intrinsic natures without human intervening. We should give attentions to both of their attributes as in natural ecosystems and in agro-ecosystems, i.e., taking full advantage of plant nutritional measures as in agro-ecosystems to solve actual survival problems of the *ex-situ* conservation plants, and ensuring the final goal of returning to nature and playing its ecological role.

Keywords: *ex-situ* conservation; ecological similarity; plant nutrition; conservation strategy

Introduction

Ex-situ conservation occupies a very important position in conserving global biodiversity (Ford-Lloyd & Maxted 1993). Botanical and forest gardens play a significant role in *ex-situ* conservation. Currently about 15 600 botanical gardens and forest gardens have been established throughout the world with 75 000 plant species collected. Those plants account for 25% of the world flora, of which 1 200 to 1 500 species are endangered. The Royal Botanical Gardens, Kew, England, cultivates about 25 000 plants (accounting for 10% of world flora), of which ICUN (World Conservation Union) believes 2 700 species are rare, vulnerable or endangered (Reid & Miller 1989). Botanic Gardens Conservation International (BGCI 2003) has published the Global Strategy for Plant Conservation and called for 60% of threatened plant species to be accessible in *ex-situ* collections, preferably in the country of origin, and 10% of those to be in-

cluded in recovery and restoration programs.

The Chinese Academy of Sciences (CAS) has drafted a 15-year master plan to guide the overall program of conserving China’s indigenous species. Its goals are to increase Chinese species presented in the 12 CAS botanical gardens from about 3 000 to 21 000 species, which would be more than two third of China’s indigenous species, and to strengthen collection of the 500 rare and endangered plant species in botanical gardens (Huang et al. 2002). In the past, *ex-situ* conservation made some efforts only in a relative small scale, which have resulted in poor growth, reproduction, or even death of a proportion of the protected species (Xu 1998; Wan et al. 2004). If plant growth or reproduction can not be guaranteed, none conservation practice can be implemented. In fact, unsuccessful *ex-situ* conservation could result in destruction of rare and endangered plant resources as well as waste of labor forces and financial resources.

The fundamental difference between *ex-situ* conservation and introduction and acclimation is that the former aims to protect and exploit plants in a sustainable way, thus it attaches importance to retain original genetic characteristics, while the latter attaches importance to the transmutation of genetic characteristics so as to satisfy various practical needs (Younge & Foukes 2003). These two strategies are so similar that some rules are borrowed from introduction or acclimation to guide *ex-situ* conservation. For instance, “Climatic Similarity Theory” was adopted in the development of *ex-situ* conservation strategy (Xu 1998; Li et al. 2002). Nonetheless, in conservation practices, due to our neglecting the factors contribution to growth and reproduction of protected species, the species unavoidably have suffered from some problems in their growth. Plants and their eco-

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logical environment are interconnected (Henry 1999; Margules & Pressey 2000). To improve the quality of *ex-situ* conservation, and to construct a useful conservation strategy, we should consider the species combining with their original ecosystem. Therefore it is reasonable to propose a comprehensive conservation strategy based on “Ecological Similarity” (Margules et al. 1994; Gemmill et al. 1998; Altmoots 1999).

The proposed nutritional strategy of plant *ex-situ* conservation based on “Ecological Similarity”

In fact biologists have worked extensively in establishing the theoretical framework of “Ecological Similarity”, but most of the work concerns the species themselves and their biological environment, such as their genetic structure and genetic risk evaluation, pollinating insects’ influences upon the breeding system, the establishment of community for *ex-situ* conservation, and so on (Simon et al. 2001; Soulé & Sanjayan 2001; Fleishman et al. 2001; Pärtel et al. 2005). Research on the abiotic environment is not systematic, and only principle application is involved (Coates & Hamley 1999; Navarro & Guitian 2002; Miyamoto et al. 2002; Richards et al. 2003). Therefore researches on abiotic environments are great desired (Van 2003).

Plant nutrient imbalance can cause serious plant growth disorders or even death. The main issue in plant nutrition research is focusing on how to provide sufficient nutritional supplies, which main methods are through improving soil fertility and providing essential mineral elements (Stewart et al. 2005). Although research on plant nutrition has extended from traditional agro-ecosystems into natural ecosystems (Yamasaki et al. 1998; Bashkin et al. 2003), it has not really extended into the field of *ex-situ* conservation for rare and endangered plants. Therefore it is absolutely necessary to perfect the conservation strategy based upon “Ecological Similarity” by adding vital plant nutrition of the abiotic environment to the “Climatic Similarity”. Its core concept is that the plants in *ex-situ* conservation, which come from natural ecosystems and are allocated in the agro-ecosystems artificially, will return to natural ecosystem ultimately. Therefore, research on the plant nutrient in *ex-situ* conservation should neither just pursue yield and quality as that in agro-ecosystems nor merely stay on the research of intrinsic natural rule without intervening. The plant attributes in both natural ecosystems and agro-ecosystems must be considered so as to find the implications for plant conservation, following the principle of “Ecological Similarity”. The research measures of plant nutrition using in natural ecosystems can solve effectively the practical problems and also conform the final goal returning to nature and playing its ecological role in identifying the research issue. The practical aim is 1) to relieve the growth disorders caused by nutrition and soil environment, 2) to provide safeguard for plant reintroduction, and 3) to provide techniques of extensive reproduction for some plants.

Plant nutrition in *ex-situ* conservation

Thousands of years ago, in Chinese ancient books, *Zhouli* stated

“Earth is for natural plant growth while soil is cultivated for human purposes”. This may indeed be the earliest definition for soil. A fundamental scientific truth illustrated in this definition is that soils are the main sources of plant nutrition (Moore 1984; Korning et al. 1994; Epstein 2004). Climate is the leading factor in determining the general distribution of plants while soil plays a secondary part (Rinaldo et al. 1995; Seyed & Gilkes 2005). But among the environmental factors in the ecosystem, soil may play a more significant role than climate in the interrelation between species. For instance, spatial heterogeneity of soil plays a remarkable role in the genetic divergence of plants (Seyed & Gilkes 2005); e.g., *Arabidopsis halleri* resistant to heavy metal stress has different genetic structures when it is exposed to various soil types and varied heavy metal contents (Van et al. 2004). At present, people can’t change climate in a large scale region for a large period, but improving local soil nutrient status is practical, and it is important for *ex-situ* conservation.

The primary standard in evaluating the success of *ex-situ* conservation: from seeds to seeds

Due to historical and realistic reasons, most of current *ex-situ* work stays at from-seeds-to-seeds level. For example, among the 45 local species transplanted into Xishuangbanna Tropical Botanical Garden of China since 1985, of 53.3% grow with vigor, of 33.3% grow with moderate vigor, while those with vulnerable growth account for 13.3%. Apparently, the single judgment method (only by from-seeds-to-seeds) of whether conservation being successful or not, is not optimistic (Xu 1998). The rather that, in obtaining these statistics, only species still living after transplantation were included. Wuhan Botanical Garden of China has established two *ex-situ* bases, respectively located in Wuhan Botanical Garden and the Jiugong Mountain Natural Reserve, Hubei Province, where a total of 244 rare and endangered plants have been collected (Chen et al. 1999). Currently, more than 300 species have been introduced to these sites, which most certainly those transplantations were conducted based on the principles in “Climatic Similarity”. From the perspective of individual and community ecology, part of the reason leading to the unsuccessful *ex situ* of rare and endangered species is that during certain growing stages, the *ex-situ* plants’ synusium and niche among the group have changed so much that they die or languish. And as the corresponding conditions are not guaranteed, the *ex situ* fails to achieve satisfactory results, such as reduction in plant growth and vigor after being transplanted, seed germination conditions not fully guaranteed, plant diseases and insect pests, etc. (Xu 1998). Still the importance of another factor (i.e., soil), has been ignored. In the *ex-situ* conservation practice following “Climatic Similarity”, soil plays a significant role in determining whether transplantation is successful or not. For instance, in the cutting propagation of *Heptacodium miconioide*, the living ratio is only 5%, whereas in its original environment, its living ratio is 95%. After fertilizing a proper amount of Mn and Mo to the soil, their germination rate great increase (Liu et al. 1999; 2001).

A higher standard in evaluating the success of *ex-situ* conservation: preservation and representation

Preservation implies that *ex-situ* plants contain all the hereditary genotypes of their own species; while representation implies that plants sampled are collected through multiple gene pools (Xu 1998). Application of such a standard ensures that *ex-situ* plants are introduced at their original distribution range. If species of different nutritional genotypes or those of genotypes suited for different soil environments, fail to be collected, the *ex-situ* strategy is not all-inclusive, meaning the original distribution range is not “representative” and the “preservation” standard also fails to be reached.

The highest standard in evaluating the success of *ex-situ* conservation: retention and presentations

Retention refers to the gene frequency retained after a certain species *ex situ*, while presentations strive for no loss of hereditary genes after species reproduction for many generations (Xu 1998). Close attention must be paid to the element of “soil” in order to attain the highest standard. Among various intricate internal factors mixed with external conditions responsible for the endangerment of some species (Murray et al. 2002; Younge & Fowkes 2003; Lozano et al. 2003), the unique soil is the dominant factor to make certain species unique or endangered (Stevanović et al. 2003). The growth of many species originated from narrow geographic ranges is rigorously limited by soil and many have lost survival potential in a more common environment after adapting to a unique environment (Rottenberg & Parker 2003). Although a new environment brings potential hereditary variability (Agrawal, 2001), rare and endangered plants may be without strong survival potential and eliminated by the environment before their potential hereditary variability is displayed (Kruckeberg & Rabinowitz 1985). Deleterious mutations accumulate more easily in small populations, producing a reduction in the intensity of natural selection (Fernandez & Caballer 2001). In other words, new environmental stress is another deleterious factor to endangered species (Murray et al. 2002). The real reason for unsuccessful *ex-situ* growth of some species may originate here, likely environment stress should be minimized to ensure success.

Besides being a refuge for rare plants, the *ex-situ* environment should prevent hereditary gene loss of transplants and keep them from acclimation. Thus the *ex-situ* environment should preserve its selective function upon rare plants (Linhart & Grant 1996; Mattner et al. 2002).

The species urgently concerned with plant nutrition in *ex-situ* conservation

A conservation strategy demands to analyze a great deal of information relevant to the species (Pärtel et al. 2005). Taking the status of plant species into consideration, it is great necessary to affirm priority order of species conservation in drawing out *ex-situ* conservation strategy on plant nutrition. (Sutherland et al.

2004). From a practical point, it is neither necessary nor possible to cover all *ex-situ* plants. How to specify species deserving prior conservation is itself a question to be studied. In response to this question, it is still necessary to return back and research the internal and external factors leading to certain species endangerment, that is, to put them back into the original ecosystem and make a comprehensive analyses, which is not a circular argumentation in logic, but just reflects the ultimate purpose of species *ex situ*: their reintroduction and the realization of their ecological functions (Henry 1999; Margules & Pressey 2000).

The species endangered by soil factors

Gardenia actinocarpa and *Gardenia ovularis* are distributed in the same range, while the former is a restricted endemic plant and the latter is widespread conqueror. Analyses of nutrient content in the leaves and growing sites of the two species indicate that the Mn content in the rare species' leaves is obviously higher than the common species; while little difference exists in soil Mn at the respective growing sites (Richards et al. 2003). The correlation analysis showed that the genetic diversity of *H. miconioides* within populations was significantly positively correlated with the soil total nitrogen (Jin & Li 2005).

The species with disappearing or narrowing distribution ranges

With the progressively increasing of human interference, the original habitats of many species have been endangered. This has resulted in rapid decrease of the number of these species. For instance, there only one *Carpinus putoensis* survives in wild, *Gleditsia japonica* var. *velutina* only 2, *Erythropsis kwangsiensis* and *Abies beshanzuensis* var. *beshanzuensis* only 3, *Acer yangjuechi* only 4, *Ostrya rehderiana* only 5, and *Manglietiastrum sinicum* only 6. These species have been in severe danger (Fu and Jin 1992). The other examples were shown as *Myricaria laxiflora*, *Adiantum reniforme* var. *sinense* and *Neyraudia wushanica* (Huang 2001). Species having very small population all need to be preferentially provided with plant nutrition conservation, as their *ex situ* can not be allowed to fail (Rottenberg & Parker 2003; Younge & Fowkes 2003).

The species endangered whether by soil factors or not being uncertain

Any construction of a list of plants needing preferential conservation tends to be influenced by researcher intuition (Sutherland et al. 2004). In fact it is necessary to have a comprehensive evaluation of species phylogeny (Tagliavini et al. 1999; González-Pérez et al. 2004), phytogeography (Moore 2002), plant ecological history (Coates & Hamley 1999). Selected plants in current *ex-situ* programs are mostly sampled randomly (Mariette et al. 2001). A species or even an individual has adapted to its original environment (Murray et al. 2002), thus the source of the species must be well considered in *ex-situ* conservation (Miyamoto et al. 2003).

The most important, effective method is to evaluate the current growth and reproduction of *ex-situ* plants

The physiological and morphological traits of plants in nutrition element shortage can be used as a ruler in evaluating the current growth and reproduction of *ex-situ* plants. For example, *Pinus elliottii*, when B is shortage, has clustered top buds and resinosis (Goddard et al. 1975). Calciphobes such as *scleranthus perennis* showed obvious symptoms of phosphorus deficiency in calcareous soil (Tyler 1996). Describing the living status of plants in *ex-situ* conservation faithfully will provide truly evaluation and valuable guidance for the research of solving the growth disorders. We assessed survival status of *ex-situ* conservation species in Wuhan Botanical Garden, and results showed that about 40% species had obstacles of growth and reproduction, to different extent. Among 23 species with worse survival status, 21 species had higher Ca and Mg, but lower N and P concentrations.

The practice of conservation strategy including plant nutrition for *ex-situ* plant growth based upon “Ecological Similarity”

Analyses of the soil from original environments and chemical element background data

Research on chemical element background data for forest plants abounds based on studies concerning air and soil pollution, or as a result of ore research and management of cultivated forests (Ricklefs & Matthew 1982; López-Mosquera et al. 2000; Mankovska et al. 2004). However, little research has been conducted on chemical element contents in rare and endangered species (Ricklefs & Matthew 1982; Rode 1993). Some research in this field has begun in recent years (Liang et al. 1998; Zhi et al. 2004) and the data obtained will provide good data for evaluating rare and endangered plant nutrient conditions under *ex-situ* conservation.

Monitoring *ex-situ* plant nutrition changes

Chemical element content in plants is primarily determined by the plant's own hereditary characteristics and secondly influenced by external factors (Hou 1982). Monitoring the changes in plant chemical element content is an important way to understand plant nutrition requirement and their nutrient hindrances (Rode 1993; Collins et al. 2005; Olness et al. 2005).

Diagnostic research upon *ex-situ* species

Plant nutrient conditions are closely related to various bio-ecological factors including morphology, phenology, etc (Huang et al. 2001; Adams & Allen 1985; Wright et al. 2001; Loveless 1961; Reich & Walters 1994; Niinemets & Kull 2003). Research in this field will provide direct evidence about rare and endangered plant nutrient deficiency, excess, imbalance, and other factors inhibiting plant growth (Glimskar & Ericsson 1999;

Niinemetts et al. 2002). As a result, the research helps to create a congenial environment in which plants may grow and reproduce prosperously.

Conclusions

The proposed strategy would add detailed considerations of native habitat soil properties and soil-plant interactions to factors evaluated in *ex-situ* conservation. This would add a more holistic view of plant conservation.

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